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RADIATION CHARACTERISTICS OF MILITARY CLOTHING OBSERVED WITH A PASSIVE DETECTION SYSTEM

by
Alvin O. Ramsley and Alfred P. Merola

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UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Organic
Materials Division
TS-140

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TECHNICAL REPORT
66-16-CM

RADIATION CHARACTERISTICS OF MILITARY CLOTHING

OBSERVED WITH A PASSIVE DETECTION SYSTEM

by

Alvin O. Ramsley and Alfred P. Merola
Textile Dyeing Branch

Project Reference: Series: TS-140
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March 1966

Clothing and Organic Materials Division
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

Throughout the ages warfare has been characterized by a dichotomy of capabilities between two adversaries. Differences in weaponry, mobility, and logistics have largely determined the outcome of the most recent large-scale wars.

Since the Korean War, however, most conflicts have taken on a radically different character. In non-conventional or guerrilla warfare, action in small, mobile groups seems the rule. It is interesting to note that the dispersal of troops required in all-out nuclear warfare would have the same result.

In either situation detection, location, and identification of individual adversaries becomes increasingly important. Simultaneously, the avoidance of detection and identification by the enemy is equally and individually important, illustrating another aspect of the fundamental dichotomy.

Great advances in electronics and optics have combined to provide an observer with a variety of tools. One of the more sophisticated of these tools is a system based on detection of infrared radiation emitted by the target itself.

This report discusses the detectability of our present field clothing, defines critical parameters, and suggests the course that materials research should take to lessen the probability of detection by passive infrared detection systems.

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Clothing & Organic Materials Division

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ABSTRACT

Among the various modern detection systems is a class of devices that are sensitive to the longwave radiation commonly emitted by any object when it is at or near body temperature. This report discusses one such commercial image-forming instrument from the perspective of its ability to detect individual soldiers.

Analysis of the characteristics of this instrument suggests that its maximum useful range is about 400 meters. In practice, it was possible to produce thermograms at ranges of up to 250 meters.

Thermograms of a simulated human figure in various states of dress were made at controlled ambient temperatures. The instrument is shown to be capable of producing images even when the figure is covered with a great amount of insulation. This suggests that efforts to reduce the radiation from a clothing assembly by reducing the temperature of its surface are not feasible. The alternative approach to reducing the probability of detection by passive infrared detection systems requires that the emittance of the surface of the garments be reduced.

STUDY OF DETECTION CAPABILITIES OF PASSIVE
INFRARED SURVEILLANCE DEVICES

1. Introduction

Camouflage in warfare is probably as old as warfare itself. Its purpose is the denial to an enemy of some of the information he needs to destroy those targets he regards as important. Camouflage may be defined as the use of materials and techniques that reduce the contrast between an object and its background to a degree that significantly decreases the probability of detection, location, and identification of the object.

The enemy observer who is familiar with the composition and characteristics of the terrain and the form and silhouette of his targets, and who can anticipate the kinds of groupings and motions that may be expected of his targets, poses a formidable threat. For daylight observation he has long been equipped with binoculars, filters, and special photographic film. Until quite recently, however, he has been restricted in his surveillance to the use of these visual methods and his effectiveness has thus been severely limited during the hours of darkness.

As the art of visual camouflage has become more effective, and information under more demanding conditions has become necessary, the science of detection has become more sophisticated. Radar[1,2] and image-converter devices sensitive to low levels of visible light[3-5] now enable an observer to detect individual soldiers at night. Moreover, there is also available a variety of surveillance devices that are sensitive to both the shorter[6-8] and longer[9-14] wavelengths of infrared radiation.

Detection systems may be classified as active or passive. When the source of radiation used in a detection system is controlled by the observer, the system is said to be active. Typical active surveillance devices are searchlights, radar, and sniperscopes. On the other hand, when the source of radiation is independent of the observer, the system is said to be passive. Direct visual observation, which utilizes daylight, and passive infrared detection systems, which utilize radiation emitted by the target itself, are included in this category.

2. Scope of Study

The present study is concerned with the radiation characteristics of military clothing, as observed with a passive detection system -- a commercial, image-forming infrared instrument (a thermograph). Various factors that influence the detectability of the target are discussed. Thermograms (thermal photographs) were obtained at two temperatures and at various ranges to show the influence of the various components of the

uniform on detectability. From the data, we have drawn conclusions about the most promising approaches to improving the camouflage of the individual soldier against passive infrared detection.

3. Parameters of Observation

The transfer of radiant energy from an object, the response by an infrared surveillance device, and the interpretation of the response by an observer are governed by four primary physical factors: detection characteristics of the instrument, radiation characteristics of the target, radiation characteristics of the background, and attenuation characteristics of the intervening atmosphere.

a. Detection Characteristics of Infrared Camera

The infrared device used in these studies was manufactured by the Barnes Engineering Company. It may properly be called a camera because it presents the final form of the data as an image on a photographic film. It is a commercial instrument and was not specifically designed to serve as a military surveillance device. In many respects, however the performance of this camera is typical of most infrared sensitive passive surveillance devices. It has been described by the manufacturer[9] and in the technical literature (10,11,13). Some of its non-military applications have also been described in popular literature[15,16].

Figure 1 illustrates the optical principles involved in the operation of the instrument. Radiation from the field of view falls on a plane target-scanning mirror and is reflected to the Cassagrainian mirrors that focus the
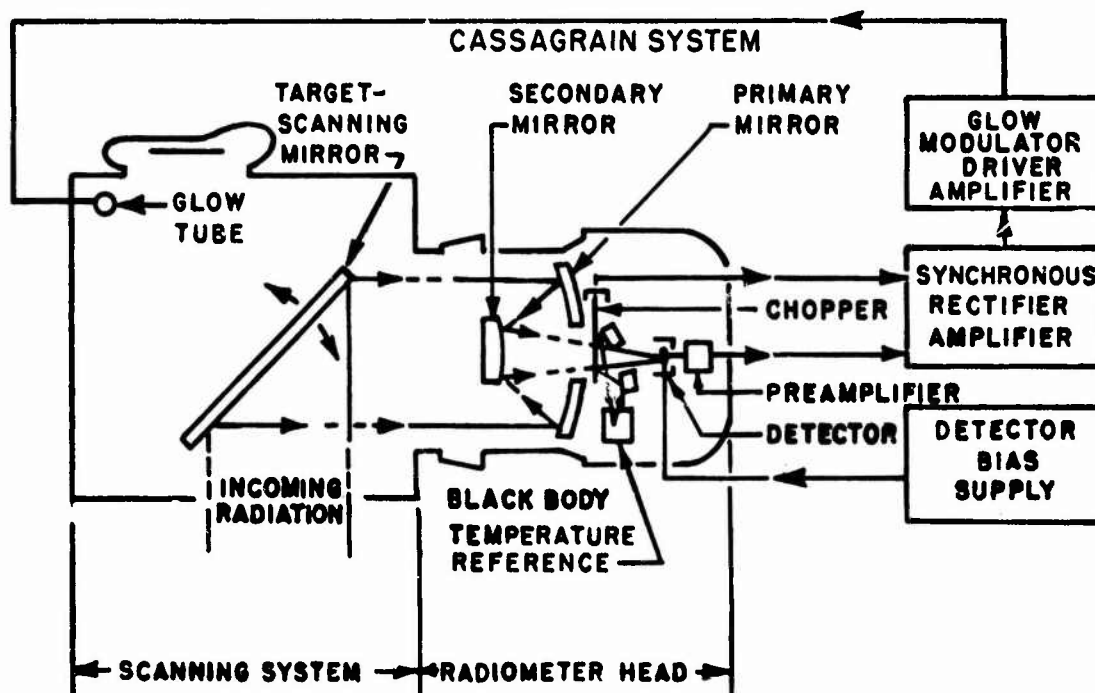
Figure 1. Schematic diagram of infrared camera showing basic optical principles.

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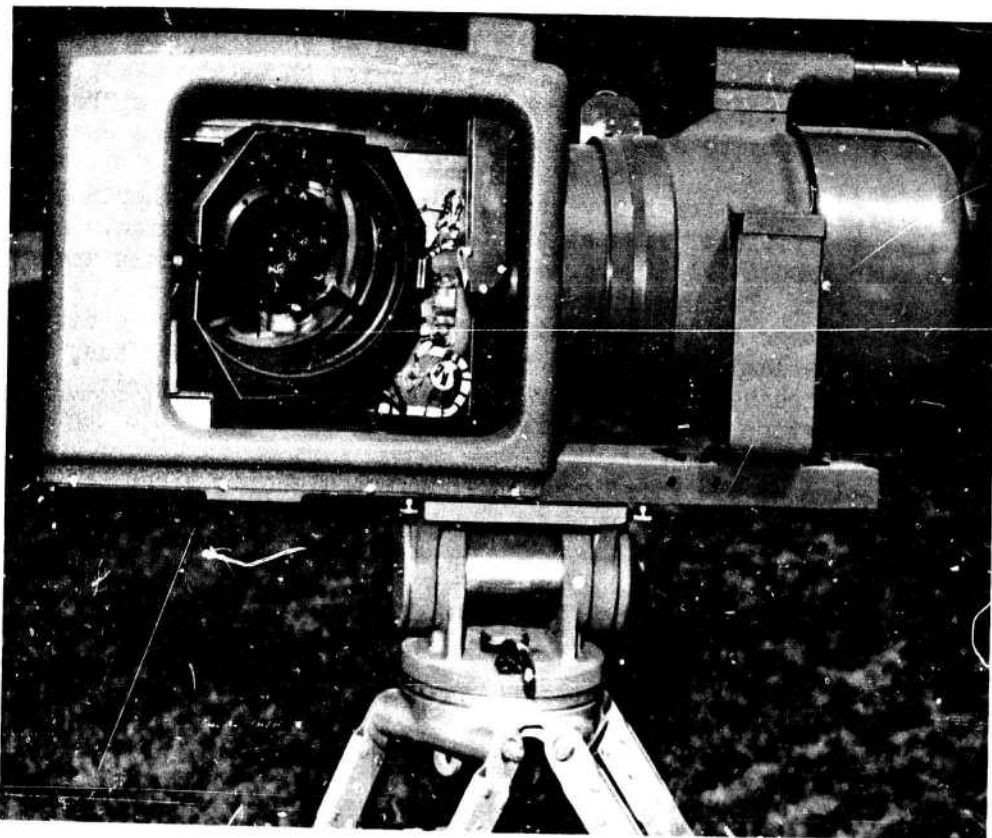
Figure 2. Target-scanning mirror and reflection of Cassagrainian
mirrors in optical unit of passive infrared camera.
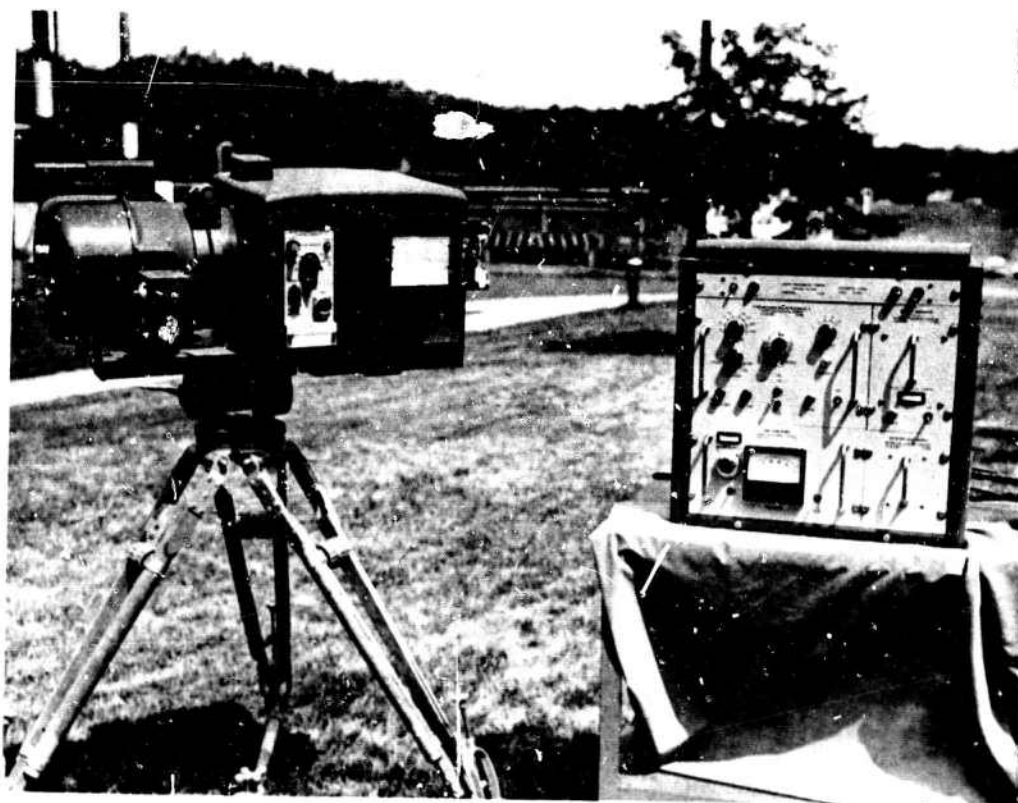
Figure 3. Complete infrared camera showing optical
and electronic units.

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energy on a germanium-immersed thermistor bolometer, 0.3 mm square, that is sensitive to radiation having wavelengths as long as about 15 microns[10]. Figure 2, which is a photograph of the optical unit, shows the Cassagrainian mirrors in the radiometer head reflected in the target-scanning mirror. Figure 3 shows the opposite side of the optical unit and also the control unit.

The target-scanning mirror covers a 10-degree field, both horizontally and vertically; the field of view at the detector is 1 milliradian. As the mirror scans once across the 10-degree field, 175 separate signals are received and amplified. The amplified signal is used to control the brightness of a lamp in proportion to the intensity of the infrared signal received. A small image of the lamp is focussed on a photographic plate. Thus, at the end of a single scan, a line is produced on the film that varies in brightness in proportion to the incoming infrared signal.

Upon completion of the first scan, the target-scanning mirror rotates upward by about 0.06 degree and repeats the scan. A small "recorder mirror" is attached to the back of the target-scanning mirror. Figure 4 shows that as the field of view is scanned by the target-scanning mirror the film is simultaneously scanned by the signal-modulated image of the lamp.
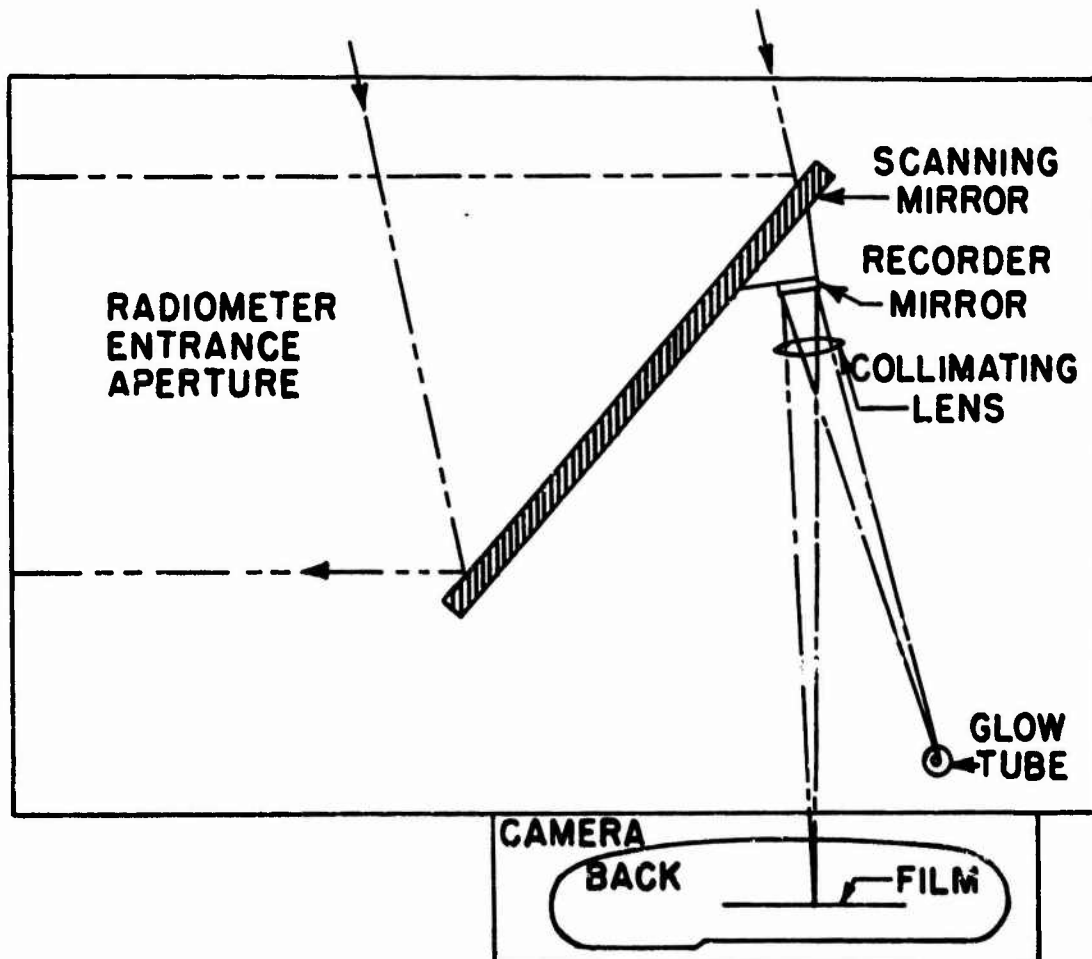
Figure 4. Schematic diagram showing optical system for producing the photographic image.

In all, 176 lines are scanned in a 10-degree vertical field, each the result of 175 signals. More than 30,000 data points are, therefore,

Figure 5. Subject photographed by emitted radiation using the infrared camera.

represented in a complete 10 by 10-degree scanning cycle. A photographic image of the field of view is thus produced. The density of any part of the photograph varies in proportion to the energy received from the radiating object being viewed. A complete scan requires 6.5 minutes.

Figure 5 represents a typical photograph obtained with the camera. Variations in brightness due to differences in emitted radiation may be evaluated by comparison with the calibrated gray scale printed at the top of the photograph. Temperature values for the gray scale are computed from an empirical formula[9] containing constants that depend on various electronic settings of the instrument, the distance from the subject to the camera, the reflection losses in the mirror system, the temperature of the internal blackbody reference, and the emittance of the object.

b. Radiation Characteristics of the Target

1) General Theory

Infrared radiation is a form of electromagnetic energy that differs from visible light only in frequency; its behavior is described by the same laws of motion, reflection, refraction, diffraction, polarization, and scattering. Because its frequency is lower (10^{13} to 10^{14} cycles per second) than that of visible light (4 to 8 x 10^{14} cycles per second), the energy per quantum of infrared radiation is correspondingly lower and hence the mechanisms for its production and absorption are somewhat different.

Electromagnetic radiation has its origin in oscillating electric dipoles. These may consist of electrons oscillating about a positively charged nucleus or throughout a whole molecule. Since the mass of the electron is low and its frequency of oscillation high, the radiation produced in this manner is usually in the ultraviolet or visible portion of the spectrum. Infrared energy is radiated when partially charged atoms within a molecule vibrate due to their thermal energy. The frequencies of the emitted radiation correspond to the frequencies of the stretching, bending, or rocking motions of the bonds in the molecule.

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The fundamental relationship in radiation theory and measurement is the Planck equation:

$$W_\lambda = \frac{2\pi c^2 h}{\lambda^5} \cdot \frac{1}{e^{ch/k\lambda T} - 1} \quad (1)$$

where W_λ = energy radiated within a wavelength band at wavelength λ

c = speed of light   k = Boltzmann constant
h = Planck constant   T = absolute temperature

In Figure 6, radiant power is plotted as a function of wavelength for an experimental "black body" radiator at various temperatures. The data points are those of Lummer and Pringsheim[17] from which Planck derived his equation.

A black body is a perfect absorber, one that absorbs all incident radiation without transmitting or reflecting any of it. A perfect absorber is also a perfect emitter, i.e., it radiates energy in accordance with the Planck Law.

Integration of Equation (1) over the entire spectrum yields the Stefan-Boltzmann equation for the radiance W_T of an object at temperature T:

$$W_T = \epsilon \sigma T^4 \quad (2)$$

where ϵ = emittance
and σ = Stefan-Boltzmann constant

A black body radiator is one in which emittance equals unity. Real surfaces, however, fall short of the requirements for black body radiation. For these, emittance is defined as:

$$T = \frac{Ws}{Wb} \quad (3)$$

where Ws = energy radiated by a given sample at temperature T
Wb = energy radiated by a black body at temperature T.

From Figure 6, it is seen that the maximum of each curve appears at progressively shorter wavelengths as the temperature increases. This relationship, called the Wien Displacement Law, is described by:

$$\lambda_{max} = \frac{2897.8}{T} \text{ microns} \quad (4)$$

Figure 6. Experimental radiation curves for a black body.*

1 - 1646°K   5 - 998°K
2 - 1449   6 - 904
3 - 1259   7 - 723
4 - 1095

*From Reference 17.

SPECTRAL RADIOSITY (ARBITRARY UNITS)

WAVELENGTH (MICRONS)

2) Nature of the Target

The signal received by an infrared surveillance device depends primarily on the temperature and emittance of the radiating surface in accordance with Equation (2). For example, let us assume that a soldier's skin and his uniform both radiate as black bodies at temperatures of 32° and $-18^\circ C$ (about 90° and $0^\circ F$). Under these conditions, Equation (2) predicts that his face will radiate about twice as much energy per unit area as his uniform. We would therefore expect to see a contrast between the face and the uniform.

Equation (4) predicts that the peaks of the spectral emission curves for the face and the uniform will occur at 9.5 and 11.3 microns, respectively. To detect this postulated difference in contrast, the sensitivity of a detector should, of course, be constant over a range that includes these wavelengths.

Since infrared surveillance devices are presumably intended for use at night, the temperature of radiating surfaces of uniforms will be determined largely by the outward flow of heat from the body and loss of heat at the surface by radiation and kinetic processes. This temperature will be influenced both by the choice of materials and by the design and construction of the uniform.

The choice of material for the outer layer will also determine the emittance of the corresponding part of the target. Table I shows the values of emissivity* of various materials as reported in the literature (18a through g). Variations in emissivity are due, at least in part, to differences in the actual samples used. Presumably, human skin has an emissivity similar to that of the materials shown in Table I (except aluminum).

Figure 5 shows that the exposed parts of the face were warmer than the other surfaces shown. Due to the greater proximity to the skin, parts of the shirt appear almost as warm as the face. The eyeglasses and tie appear comparatively cool because they were separated from the body, which is the source of heat. The eye region actually radiates at a high level but the high absorbance of glass blocks this radiation effectively.

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* The suffix "-ivity" is used for the intrinsic properties of a substance; the suffix "-ance" is used for the properties of a specific body and may be influenced by its size, shape, and surface conditions.

TABLE I

Total Emissivity of Various Materials

	Emissivity	Reference[18]
Wood	0.90 - 0.94	a, b
Paper	0.92 - 0.94	a, b
Various paints	0.89 - 0.96	c
Various plastics	0.79 - 0.83	d
Various clear lacquers on aluminum foil	0.70 - 0.92	e
Cotton cloth	0.77	f
Silk cloth	0.78	f
Wool cloth	0.78	f
Polyester fabric	0.86 - 0.90	g
Nylon	0.85 - 0.88	g
Aluminum	0.22	a, b

c. Radiation Characteristics of the Background

Detectability by infrared surveillance devices is influenced not only by the radiance of the target but also by the radiance of the various elements that make up the background against which the target is viewed. Table II shows typical data for the emissivity of background materials that have been reported in the literature[18a through h].

TABLE II

Total Emissivity of Typical Terrain Components

	Emissivity	Reference[18]
Soils, wet or dry	0.92 - 0.96	h
Quartz	0.90	h
Snow	0.82	h
Ice	0.89 - 0.96	h
Rime frost	0.985	h
Wood	0.90 - 0.94	a, b
Various paints	0.89 - 0.96	c
Brick, mortar	0.93	a
Glass	0.95	c

Since leaves consist primarily of water and carbohydrates, one can reasonably assume that their emissivity is high. However, a leafy

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background, especially when viewed horizontally, consists of voids as well as leaves. The emissivity of such a background is probably lower than that of the leaves alone. A comparable effect is found in the reflectance of a terrain that is illuminated horizontally by a point source such as is used with a sniperscope[19].

It should be obvious that no device, infrared or otherwise, can differentiate an object from its surroundings if it receives identical signals from both. Unfortunately for the target, this situation rarely occurs because the temperatures and emittances that determine the radiance of a uniform and the exposed parts of a man's body are usually different from those of the terrain. To repeat, in order for an object to be visible in any sense, a difference must exist between the signals from the target and the background and this difference must be discernable. For visual observation, this concept is termed "contrast", and is defined[20] as

$$C = \frac{B_2 - B_1}{B_1} \qquad (5)$$

where B_1 = luminance of the background

B_2 = luminance of the object

For the purpose of this study, we shall extend the term "luminance" to include the radiance of the scene that is scanned*. Replacing B by W_T from Equation (2) we can then rewrite Equation (5) to define intrinsic contrast at the target C as

$$C = \frac{\epsilon_2 T_2^4 - \epsilon_1 T_1^4}{\epsilon_1 T_1^4} \qquad (6)$$

d. Factors that Degrade the Image

Equations (5) and (6) are expressions of the intrinsic contrast at the target position of the objects viewed. However, it is the apparent contrast among the signals received by the observer that determines their usefulness. Intrinsic contrast is modified by any factor that tends to equalize the signals from the areas to be compared or that tends to diffuse the line of demarcation between adjacent areas. These factors include losses in signal strength within the instrument; limitations on its resolution; absorption, scattering, and radiance of the atmosphere; and motion of the target.

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*The quantitative measurement of luminance includes the visual sensitivity function of the human eye. Extension of the concept to include radiance should take into account the spectral sensitivity of the detector, which in this case is nearly constant to 15 microns[10].

1) Limitations of the Detector

The various mirrors in the instrument are front-surface mirrors of high reflectivity. Nevertheless, a loss in sensitivity of about 10% may be attributed to them[9].

The resolution of the detector, by limiting the smallest image that can be clearly defined, affects the sharpness of the image and limits the range over which the instrument can detect an object of a given size. The camera used in this study has a field of view (for each impulse received by the detector) of 1 milliradian. A man 2 meters tall and standing 400 meters from the instrument subtends an angle of 5 milliradians. His width, however, is in the order of 0.5 meter, corresponding to about 1 milliradian, which is equal to the field of view of the detector. Under these conditions, his image will be blurred and the ultimate contrast sharply reduced. All of the NLABS experiments were carried out with target-to-detector distances of less than 400 meters, a distance that may be considered as the upper limit for detecting individual soldiers with this instrument.

2) Influence of the Atmosphere

When signals pass from the target to the detector, some of the energy will be absorbed by particles of dust, droplet of water, and certain of the atmospheric gases; some of the energy will be scattered by the solid and liquid particles in the atmosphere; only the remainder will be transmitted.

Scattering of radiation degrades the image by deflecting part of the signal out of the line of sight. It causes both a weakening of the signal and a blurring of the image. Figure 7 is a curve by Altshuler[21], that shows the transmittance of a 1-km atmospheric path through the useful infrared. This curve neglects absorption. For hazy conditions in which the meteorological range (M.R.) is less than 7 km (about 4.5 miles), scattering would be more severe.

In the distortion of the signal received by the thermograph at the ranges considered here, attenuation due to absorption of energy by certain atmospheric gases is usually more significant than that due to scattering. The most important gases are water vapor and carbon dioxide. For the short ranges we are considering, absorption due to ozone, nitrous oxide, and carbon monoxide may be neglected because of the low concentration of those gases at ground level. Oxygen, nitrogen, and argon do not absorb radiation at the wavelengths here considered.

Figure 8, calculated from the data of Altshuler[21], shows the transmittance of a 400-meter atmospheric path at sea level and considers water vapor and carbon dioxide as the absorbing species. (Taylor and Yates[22] have reported similar data at a higher resolution for a
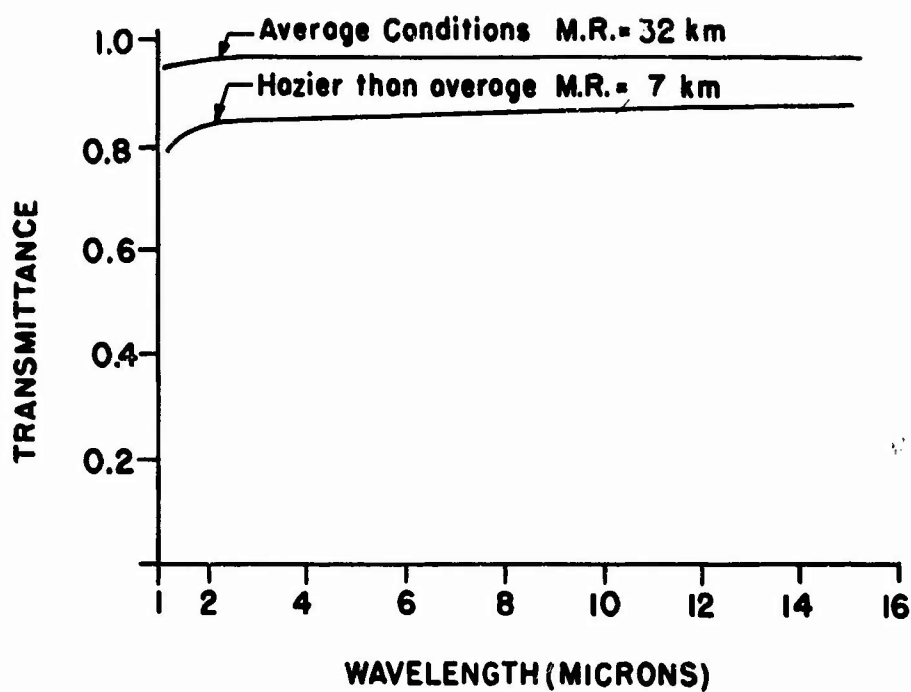
Figure 7. Attenuation due to scattering of atmosphere over one-kilometer path.[*] M.R. is meteorological range.
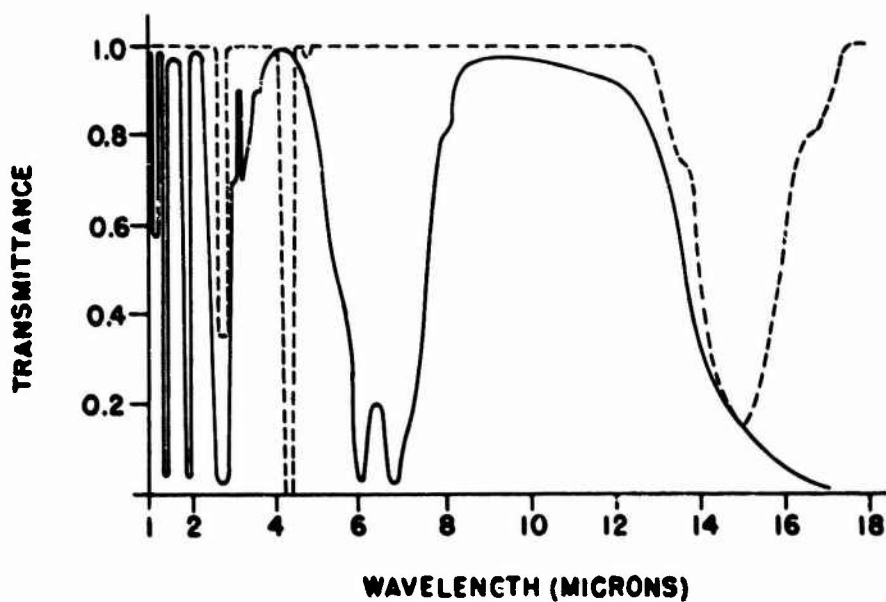
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[*] From Reference 21.

Figure 8. Transmittance curve of atmospheric gases over 400-meter path for relatively clear conditions.[*]
Solid Curve: CO_2 (1 cm - atm - km^{-1})
Dashed Curve: H_2O (1 precipitable cm)

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[*]From Reference 21.

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1000-foot path.) Altshuler's curves show that the atmosphere is most transparent to radiation in the spectral region between 8 and 12 microns. Fortuitously or otherwise, this region corresponds to that for the maximum emission of black body radiation from objects in the range of temperatures characteristic of the human body and of ordinarily observed terrain. Earlier studies that are especially pertinent here are those by Gebbie, Harding, Hilsum, Pryce, and Roberts[23], Elder and Strong[24], and Howard, Burch, and Williams[25]. Allards law for the visibility of light sources[20], shows that the illuminance E (comparable to irradiance at the detector) depends on the radiance of the target I, the distance r, and a combined scattering and absorption coefficient S, by

$$E = \frac{I}{r^2} e^{-Sr} \qquad (7)$$

The atmosphere itself radiates energy in a manner comparable to the ground. Figure 9, taken from part of Figure 4 in a paper by Bell, Eisner, Young, and Oetjen[26], shows spectral radiances measured at various angles of elevation above the horizontal. The data were obtained at Cocoa Beach, Florida, in a clear atmosphere. Superimposed on our Figure 9 are data (taken from their Figure 3) obtained at Pike's Peak, Colorado[26]. The measurements at 0 and 1.8 degrees from the horizontal are for very long path lengths. Figure 9 also shows that radiance measured at 90 degrees (for a shorter path length), is low in the spectral regions of atmospheric windows. Because our observations were made against a terrain background at maximum ranges of only 250 meters, it is concluded that radiance of the atmosphere may be neglected in this study.

Figure 9. Spectral radiance of sky at 0°, 1.8°, and 90° elevation. Solid curves (Cocoa Beach, Florida, air temperature 27°C); dashed curves (Pike's Peak, Colorado, air temperature 8°C).

The net effect of the influence of the atmosphere on the signal results in an ultimate image having less contrast with its background. Absorption weakens the signal, radiance of the atmosphere adds to both B_1 and B_2 of Equation (5), and scattering diffuses the image. In the present studies, we examined briefly the effect of distance under a given set of atmospheric conditions. In most of our work, however, observation ranges were short enough (less than 200 meters) to minimize atmospheric effects.

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3) Motion of the Target

The long scanning period of this particular infrared detection instrument requires that the subject be immobile to assure well-defined images. Even the relatively small motions characteristic of a "motionless man" result in larger but fainter and more blurred images. The rapid and large-scale motions of a man walking across the field of view laterally result in the complete loss of image.

Thus, an instrument with characteristics similar to those of the camera used in this study can not be used effectively in surveillance against troops. However, as discussed later, instruments of this type can be designed so as to yield useful information, particularly if less detailed information is acceptable.

4. Experimental Studies

a. Effect of Distance

A limited study was made of the influence of distance on the detectability of human subjects and on the quality of the image produced. Thermograms were made with the subjects wearing civilian clothing (including short-sleeved sport shirts) at distances of 18, 60, 150, and 250 meters (Figs. 10 - 13), and with the subjects standing as motionless as possible. The exposures were made in New England 1 to 2 hours after sunset on a summer evening (temperature 22.5°C, 80% r.h.).

These thermograms reveal that, at 250 meters, the subject is discernible as a faint but distinct spot against a uniform background. We conclude that, for the Barnes Camera, the range maximum of 400 meters that was derived from the characteristics of the instrument (see Section 3.d.1) is reasonable. The balance of the study, however, was carried out at a much shorter distance (13 meters) to permit more detailed data.

b. Effect of Ambient Temperature and Clothing

1) Measurement Procedure

We have shown, in Equation (6), that the temperature of a surface and its intrinsic nature, as is shown by its emittance, will determine its detectability by an infrared detector. In this study, we made use of a heated manikin clothed in various articles of military apparel to obtain data that could lead to the eventual development of camouflage against passive infrared systems.

The manikin was made of sheet copper about 1/8-inch thick and was formed in the shape of a man about six feet tall. Electrical heating wires located inside maintained the surface at temperatures comparable to those of human subjects. The surface of the "copper man" was painted black,

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Figure 10.   Thermogram at 18m
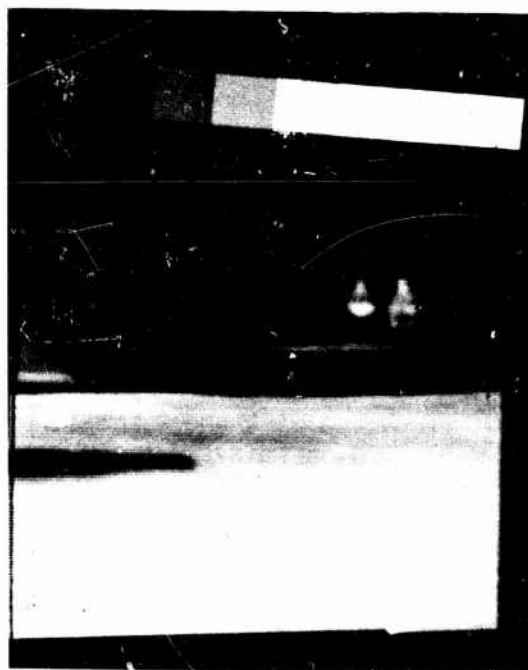1 hour after sunset
Dry bulb 22.5, wet bulb 20°C

Figure 11.   Thermogram at 60m
1-1/4 hours after sunset
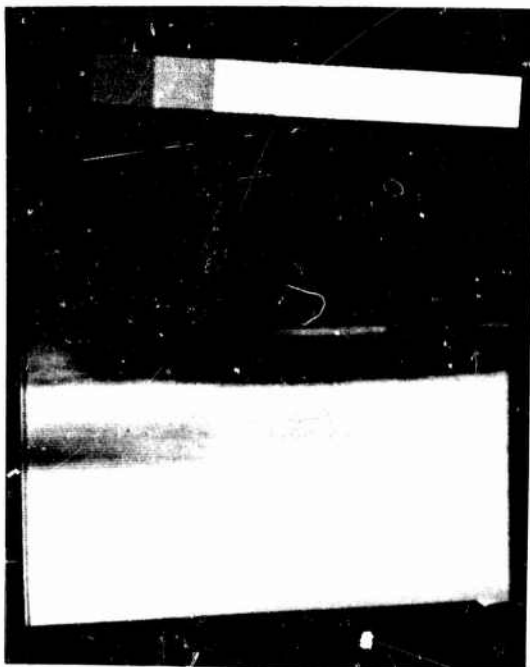Dry bulb 22.5, wet bulb 20°C

Figure 12.   Thermogram at 150m
1-1/2 hours after sunset
Dry bulb 22.5, wet bulb 20°C

Figure 13.   Thermogram at 250m
2 hours after sunset
Dry bulb 22.5, wet bulb 20°C

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using a formulation specifically selected for its high emittance that is comparable to that of human skin[27]. Figure 14 shows the copper man without clothing and Figures 15 through 18 show the manikin in the various clothing assemblies considered in this study.
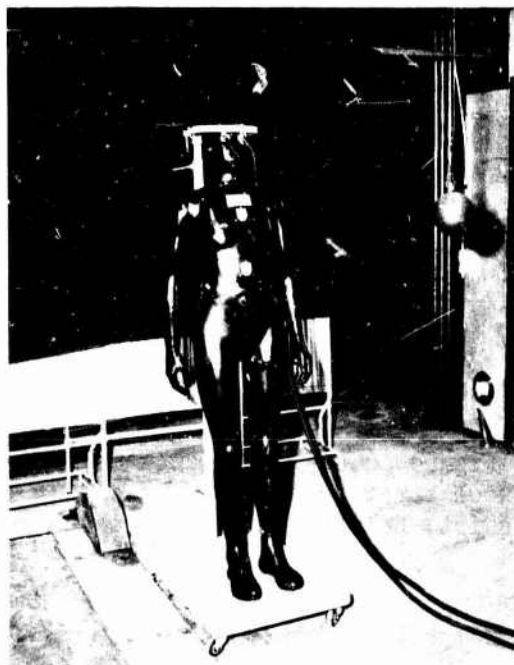
Figure 14. Copper man without clothing

The studies were carried out in a large arctic climatic chamber in which constant ambient temperatures could be maintained over an extended period. A series of thermograms were made at each of two ambient temperatures: $8^{\circ}C$ and $-8^{\circ}C$ ($\pm 0.5^{\circ}C$).

2) Measurements at $8^{\circ}C$

Figures 19 through 24 illustrate the thermograms taken at $8^{\circ}C$. The captions describe the clothing worn. Average thermocouple temperatures of the various parts of the manikin during exposure are summarized in Table III. To estimate the relative effectiveness of the various articles of clothing in defeating the sensing system of the camera, a calibrated gray scale is printed at the top of each of these figures. The calibration of the scale, shown in the captions, is based on an assumed emittance of 0.95, which in turn is based on the data of Tables I and II and the fact that the paint covering the manikin was selected for its high emissivity. The gray scale temperatures for some of the figures differ from the others because certain electronic parameters were changed to produce photographs with better contrast. Changes, as noted in the captions, were also made in the clothing, such as replacing the helmet with a wool cap or covering the face with an insect netting.

One would expect the manikin to radiate more energy and thus appear brighter while unclothed, as in Figure 19. Data from the internal thermocouples (Table III) show that this was not the case; the unclothed manikin's surface temperatures were far below those observed with the clothed manikin. The addition of only underwear, socks, and cap (Figure 20) is shown to raise the manikin's temperature by about $10^{\circ}C$. It is clear that the rate of heating the manikin was inadequate to maintain proper temperatures unless it was clothed to some degree.

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Figure 15. Copper man wearing
wool-cotton underwear and socks
and a wool cap

Figure 16. Copper man wearing
wool serge trousers, wool-nylon
shirt, helmet, and arctic boots
over items of Figure 15

Figure 17. Copper man wearing
lined field jacket, lined field
trousers, and gloves over items
of Figure 16

Figure 18. Copper man wearing
field cap (helmet removed), arc-
tic parka and liner, arctic trous-
ers and liner, and arctic mittens
over items of Figure 17

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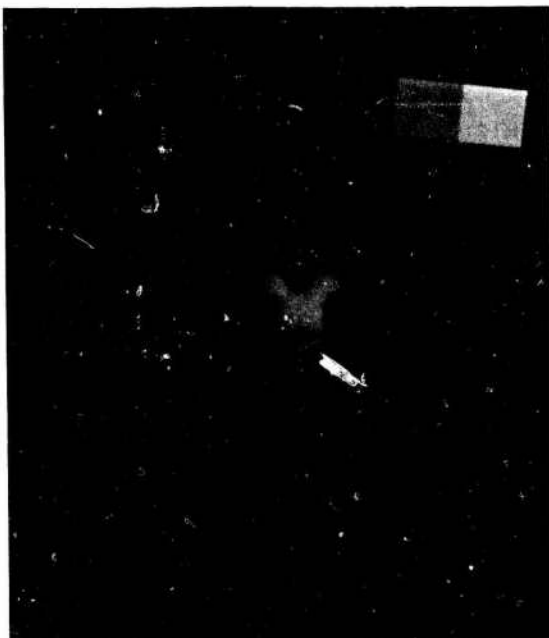
Figure 19. Copper man without clothing, at 8°C

Scale (°C): 13.2, 13.7, 14.4 15.3, 16.7, 17.0, 18.3, 20.2.

Figure 20. Copper man wearing heavy winter underwear, socks, and wool cap, at 8°C

Scale (°C): 13.2, 13.7, 14.4, 15.3, 16.7, 17.0, 18.3, 20.2.

Figure 21. Copper man wearing underwear, OG-108 wool trousers and shirt, socks, boots, and helmet, at 8°C

Scale (°C): 10.3, 10.8, 11.4, 12.5, 14.0, 14.3, 15.5, 17.5.

Figure 22. Copper man dressed as in Figure 21 except that a nylon insert net covers his face and the helmet replaces the wool cap, at 8°C

Scale (°C): 10.3, 10.8, 11.4, 12.5, 14.0, 14.3, 15.5, 17.5.

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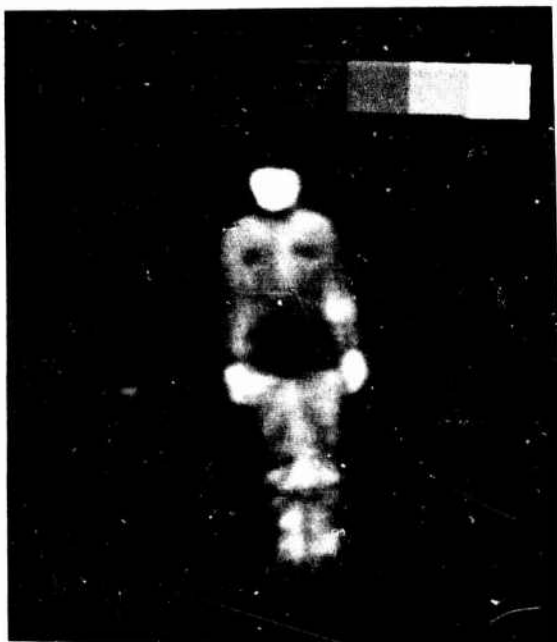
Figure 23. Copper man wearing under-
wear, gloves, wool shirt and trou-
sers, lined field jacket and trou-
sers, socks, boots, and helmet,
at 8°C
Scale (°C): 9.2, 9.6, 10.3, 11.4,
12.8, 13.2, 14.3, 16.5.

Figure 24. Copper man wearing under-
wear, wool shirt and trousers, lined
field jacket and trousers, lined arc-
tic trousers, parka, socks, boots,
gloves, and arctic mittens, at 8°C
Scale (°C): 9.2, 9.6, 10.3, 11.4,
12.8, 13.2, 14.3, 16.5.

Study of Figures 19 through 24 shows that surface temperature, and
hence detectable infrared radiation, was lower in the regions of multiple
layers. The effect of areas where shirts and trousers over-lap is shown
most clearly in Figures 20, 23, and 24.

When the manikin was more adequately clothed and overall temperatures
had reached more "normal" levels, the exposed parts of the body radiated
much more than clothed areas. This is especially noticeable in Figure 24.
Comparison of Figures 21 and 22 shows that a substantial reduction in the
brightness of the face can be effected by using as simple a device as face
netting. The netting apparently absorbs and diffuses some of the infrared
radiation emitted by the face.

Another observation, which is familiar but is nevertheless of interest
here, is illustrated in most of the photographs. The temperature of the
surface of the uniform was highest in the areas where the garments were
compressed. Thus the hips, where draw strings hold the jackets in place,
and the shoulders, which bear the weight of the upper clothing, usually
appear brighter than most of the other areas covered by the uniform.

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TABLE III

Average Internal Thermocouple Temperatures ($^\circ$C) of the
Copper Man Recorded During Each Photograph Taken at 8°C

			Figure Number			
Region	19	20	21	22	23	24
Back of head	18.1	26.5	25.0	25.0	26.5	24.7
Top of head	18.6	27.0	25.3	25.0	26.5	24.7
Right breast	18.1	29.0	33.3	33.0	32.5	33.0
Left shoulder blade	19.1	30.0	34.2	34.2	33.0	33.6
Left kidney	18.3	29.5	34.2	34.4	33.0	33.9
Right abdomen	16.7	28.4	33.6	33.9	33.0	33.6
Right buttock	16.1	26.7	33.0	33.0	32.8	33.3
Front right thigh	14.7	24.7	31.1	31.4	32.2	32.2
Back right thigh	14.7	24.1	30.0	30.0	31.7	31.7
Back right calf	16.1	24.7	30.9	31.1	31.1	31.4
Front left thigh	15.0	24.5	31.1	30.3	31.7	32.2
Back left thigh	14.7	23.6	30.3	30.5	31.7	31.7
Back left calf	15.6	24.0	30.3	30.5	30.0	30.5
Right instep	17.5	24.7	39.5	39.8	29.5	31.1
Left instep	15.8	23.4	34.4	34.7	26.1	27.8
Right triceps	15.3	23.0	27.2	27.2	30.3	30.0
Right front forearm	14.2	22.2	24.5	24.5	29.5	28.6
Back right hand	13.9	15.9	17.0	17.0	27.2	25.3
Left triceps	16.1	25.3	30.0	30.0	30.9	31.1

3) Measurements at -8°C

A series of photographs was also made with the air temperature
at -8°C (Figs. 25-28). Here we considered only those clothing assemblies
in which the copper man was quite heavily dressed.

A confusing anomaly is found in Figures 27 and 28 where the face
appears "cold". The electronic controls of the camera were at the same
setting for Figures 25 and 26, but for Figures 27 and 28 the sensitivity
was increased. When this was done, the signal from the face and hands
(Fig. 27) extended beyond the range of the instrument for the settings
used. Since the signal was shut off automatically whenever it extended
beyond the proper range, the face and hands appear black although,
actually, these areas should appear very bright. In Figure 28, the face

Figure 25. Copper man wearing heavy underwear, wool shirt and trousers, lined field jacket and trousers, pile cap, and wool gloves, socks, and boots, at -8°C.
Scale (°C): 0.8, 1.4, 1.9, 3.2, 4.8, 5.2, 6.5, 8.6.

Figure 26. Copper man wearing heavy underwear, wool shirt and trousers, lined field jacket and trousers, lined arctic parka and trousers, pile cap, and wool gloves, socks, and boots, at -8°C.
Scale (°C): 0.8, 1.4, 1.9, 3.2, 4.8, 5.2, 6.5, 8.6.

Figure 27. Copper man wearing field clothing as in Figure 22, at -8°C.
Scale (°C): 3.2, 3.4, 3.7, 4.1, 4.6, 4.9, 5.3, 6.3.

Figure 28. Copper man wearing full arctic uniform as in Figure 23, at -8°C.
Scale (°C): 4.6, 4.9, 5.2, 5.7, 6.2, 6.4, 6.9, 7.8.

does appear bright but this is presumably because the fur ruff on the parka attenuated the radiance to levels that were within the range of the instrument. Table IV contains data comparable to those in Table III but for measurements made at -8°C.

TABLE IV

Average Internal Thermocouple Temperatures (°C) of the
Copper Man Recorded During Each Photograph Taken at -8°C

	Figure Number			
Region	25	26	27	28
Back of head	22.8	29.2	23.1	28.9
Top of head	22.2	29.2	22.2	28.9
Right breast	34.7	34.7	35.0	33.9
Left shoulder blade	35.8	35.5	35.8	34.7
Left kidney	36.4	35.5	36.4	34.5
Right abdomen	35.5	34.7	35.7	33.6
Right buttock	34.7	33.9	35.0	33.2
Front right thigh	32.8	32.2	33.1	31.9
Back right thigh	31.9	31.4	32.2	31.4
Back right calf	31.1	29.5	31.4	30.3
Front left thigh	32.8	32.8	33.2	31.9
Back left thigh	32.2	31.7	32.5	31.4
Back left calf	30.2	28.6	30.3	28.9
Right instep	31.1	24.5	31.4	26.7
Left instep	25.6	20.5	25.8	22.2
Right triceps	30.5	30.5	30.3	30.8
Right front forearm	27.8	29.2	28.3	29.5
Back right hand	20.8	26.1	21.1	26.7
Left triceps	31.1	31.1	31.3	31.3

4. Discussion and Conclusions

The thermograms and data presented show that, under the conditions of this study, a passive infrared surveillance device such as the Barnes Camera is amply sensitive to detect a clothed soldier in cool surroundings regardless of how much clothing he wears. At the shorter ranges, the resolution of this particular device is also adequate to identify an object as human.

It is shown that, as the viewing distance increases, an observer finds it more difficult to both detect and identify a target. The signal, even from a stationary target, becomes weaker due to absorption and the image becomes more blurred due to scattering.

In addition to the distortion of images by atmospheric attenuation, other complicating factors are shown to be present. The simple detection of an object that is warmer than its immediate surroundings does not provide sufficient information for its identification. Objects other than human beings, such as large boulders, may radiate more energy than their surroundings, especially in the hours immediately following sunset. Without higher resolution than is available in the present instrument, such objects would confuse the interpretation of a thermographic record. The prevalence of such features in most natural terrains makes it probable that observations must often be made against a variegated thermal background.

The commercial instrument used in this study was specifically designed to produce images of stationary objects for permanent record. Since a complete image record requires 6.5 minutes, any motion by the object will be observed as distortion. Thus a soldier walking across a field of view produces an image consisting of a group of unconnected lines. For this reason, this particular instrument cannot be considered as a field-applicable surveillance device. A similar instrument[14], manufactured by Texas Instruments, Inc., appears to be comparable to the Barnes except that it completes a 10 by 20-degree thermogram in 2 minutes. Its range of effectiveness in detecting personnel is also limited to less than 400 meters.

It is very probable, however, that passive infrared surveillance instruments can be designed that sacrifice the image-forming capability or sensitivity for speed in scanning a scene. Ivanov and Tyapkin[11], briefly describe infrared direction finders and other devices that detect and make use of infrared signals without forming an image of the total field that they scan. Their optical characteristics are similar to those of the thermograph used in this study, differing primarily in the manner in which they use the signals. A device of this type can track a moving "hot" object but cannot directly identify it. However, a competent observer who is familiar with the terrain and the instrument could undoubtedly draw useful conclusions from the data obtained with such an instrument. It is possible, therefore, for infrared surveillance to take advantage of the motion of a target rather than to be defeated by it.

Passive infrared surveillance systems, like other systems, have certain advantages and disadvantages. One may assume that, because of their complexity and sophistication, they would be used only in situations where specific advantage can be taken of their unique capabilities. A comparison of their characteristics with those of other detection systems suggests what some of these situations might be.

Passive infrared systems are particularly suited for defensive combat situations. As an example, guerrillas or counter-insurgents could effectively use them in the perimeter defense of a temporary camp to guard against enemy infiltrators. It is important that the defenders preserve their cover and concealment as long as possible. Although radar devices may be more sensitive, they have the disadvantage of being active systems. Even simple devices in the hands of attacking troops can reveal the source of the radiation of active systems and hence the location of the camp itself. Hence, one significant advantage of the passive infrared surveillance system is that it emits no distinctive signal.

Another advantage of the infrared system is its ability to function in total darkness. Although visual methods are far superior both in resolution and in range, especially when aided by binoculars, their use is limited to illumination levels that are fairly high (e.g., bright moonlight). Figures 12 and 13 show the subject 150 and 250 yards from the camera, respectively. Standing in the open and with the moon shining, he could have been easily identified with binoculars. However, had he been wearing dark clothing or had he moved into a shadow, his detection by visual methods would have been unlikely.

The principles that reduce the probability of detection of troops approaching an entrenched enemy at night by passive infrared surveillance devices have been defined in Equation (6). It is important to note that the only terms in this equation that can be controlled are the temperatures and the emittances of the clothing and other target surfaces.

If we consider uniforms for cold climates, it may be practical to consider increasing the insulation of various parts of the clothing system. Figure 23 shows that the face and knit gloves radiate conspicuously. There is no doubt that a properly designed face mask and more insulation in the gloves would reduce the radiance of these regions and thereby reduce the contrast. In fact, Figure 24 shows that the simple countermeasure of added insulation afforded by the arctic mittens reduces the radiance from the hands to a level that is comparable to that from most of the other parts of the body. If other factors did not impose practical limits, the radiance of the uniformed soldier might be reduced simply by the use of additional insulation. However, since much effort has already been expended to improve the thermal insulation of clothing within the requirements imposed by mobility and weight, the improvements offered by this approach are not encouraging.

Uniforms for hot climates present a different problem. Since the soldier must get rid of a large quantity of heat, efforts to reduce the probability of his detection by increasing the insulation of hot-weather clothing are totally unrealistic. Other means must be sought.

As shown in Equation (6), the only alternative means of reducing the radiance of a target is to decrease the emittance of its surface. As an example, let us estimate a temperature difference of 10°C between the

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target and background, and an average emittance of 0.8 for the background at 27°C (300°K, 80.6°F). To obtain minimum contrast, the emittance of the target should then be about 0.7.

Therefore, of the two possible methods of decreasing contrast, it appears that reducing the emissivity of materials that constitute the surface of uniforms is the more promising. Although available data indicates that present textile materials have high emissivity, materials do exist (e.g., aluminum) that have emissivity values as low as 0.2. While at present it is true that practical methods of reducing the emittance of existing fabric structures are not known, it is reasonable to expect that research could lead to methods or materials that would form the basis for affording camouflage protection against passive infrared surveillance.

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13. ABSTRACT

Among the various modern detection systems is a class of devices that are sensitive to the longwave radiation commonly emitted by any object when it is at or near body temperature. This report discusses one such commercial image-forming instrument from the perspective of its ability to detect individual soldiers.

Analysis of the characteristics of this instrument suggests that its maximum useful range is about 400 meters. In practice, it is possible to produce thermograms at ranges of up to 250 meters.

Thermograms of a simulated human figure in various states of dress were made at controlled ambient temperatures. The instrument is shown to be capable of producing images even when the figure is covered with a great amount of insulation. This suggests that efforts to reduce the radiation from a clothing assembly by reducing the temperature of its surface is not feasible. The alternative approach to reducing the probability of detection by passive infrared detection systems requires that the emittance of the surface of the garments be reduced.

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